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A television studio montage amplifier.

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Naval Postgraduate School

A TELEVISION STUDIO MONTAGE AMPLIFIER

BY

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-

J. A. Cooper.

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MONTAGE AMPLIFIER

by

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PREFACE

The object of this paper is to describe in detail the electronic design of the MONTAGE AMPLIFIER. The theory of operation and its use as a special effects amplifier in commercial television studios will be discussed. This equipment was developed by the writer in the Broadcast Studio Engineering Section of the General Electric Company, Syracuse, New York, during the 1950 winter term. The writer wishes to express his gratitude to the engineering staff of the Broadcast Studio Section for their kind assistance in the development of the MONTAGE AMPLIFIER. He desires to express his sincere appreciation to Mr. Winslow L. Hurford, who originally conceived the idea of the MONTAGE AMPLIFIER, for his kind assistance and technical advice.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLE OF SYMBOLS AND ABBREVIATIONS

a-c	alternating current
Acc.	accelerator
C	capacity
C_c	coupling capacitor
d-c	direct current
e	voltage
E_c	grid voltage
E_{cc}	grid bias voltage
e_g	grid signal voltage
f_2	upper cutoff frequency
G	conductance
g_m	transconductance (grid 1 to plate)
i	current
K	thousand ohms
l	inductance
L_o	shunt peaking inductance
ma.	milliamperes
meg	million ohms
mc.	megacycles
Q-point	operating point
R	resistance
R_L	load resistance
r.m.s.	root mean square
R_o	characteristic resistance

r_p	dynamic plate resistance
V.	volts
W	watts
X_c	capacative reactance
Z	impedance
$\cong$	approximately equal to
μ	amplification factor
μf	microfarads
$\mu\mu f$	micro-microfarads
μh	microhenry
Ω	ohms
τ	circuit delay

CHAPTER I

INTRODUCTION

The MONTAGE AMPLIFIER derives its name from the well known photographic technique of super-imposing one picture, with a well defined outline, onto a background picture from another source. The function of the MONTAGE AMPLIFIER is to accomplish this superposition electronically. It has been designed for use in television studios where it may serve, for example, to effect the insertion of advertising copy onto a background picture. As in the photo-montage, it is desirable to have the resultant image free from a "double-exposed" effect in the area occupied by the inserted image.

Referring to the block diagram (Figure 1) it is seen that the amplifier is supplied with three video inputs called the NO. 1 VIDEO, the NO. 2 VIDEO and the CONTROL VIDEO. Provision is made for the NO. 2 VIDEO signal to also act as the CONTROL-VIDEO signal as required in the montage use of the equipment. A path is provided for the NO. 1 VIDEO signal to proceed via the NO. 1 VIDEO AMPLIFIER, NO. 1 MIXER, SERIES CLIPPER, and FEEDBACK AMPLIFIER directly to the output. In like manner, the NO. 2 VIDEO signal goes through a VIDEO DELAY LINE, NO. 2 VIDEO AMPLIFIER, and the NO. 2 MIXER where it joins the NO. 1 channel at the SERIES CLIPPER, then on to the common video output circuit. The NO. 2 VIDEO INPUT may also be fed to the CONTROL VIDEO AMPLIFIER where it proceeds to the two video mixers via

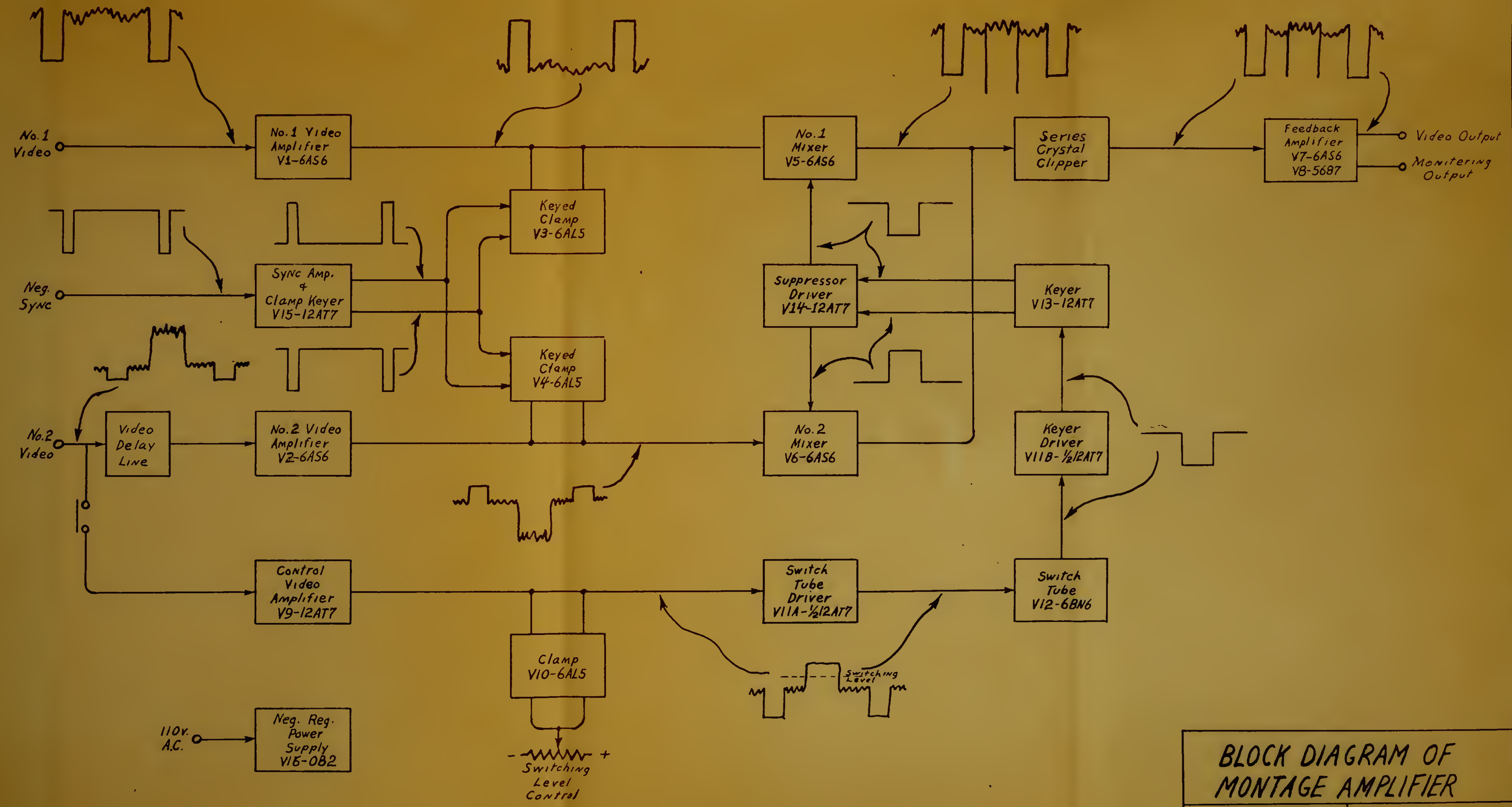
SWITCH TUBE DRIVER, SWITCH TUBE, KEYER DRIVER, KEYER, and and SUPPRESSOR DRIVER. In this CONTROL channel the NO. 2 VIDEO signal undergoes severe wave shaping, finally arriving at the two mixers as rectangular pulses of constant magnitude. These pulses serve as an "on-off" control for the mixers. The pulses fed to the two mixers are in phase opposition so that either one or the other mixer is conducting at any one time, never both.

Supporting or auxiliary circuits include a NEGATIVE SYNC INPUT followed by a SYNC AMPLIFIER, CLAMP KEYER, and the KEYED CLAMPS. One of these KEYED CLAMPS is provided for each mixer input. The purpose of this circuit is to restore the d-c component to the video signals at the input of the mixers. In a like manner a simple clamp is provided in the CONTROL VIDEO channel to set the d-c component of the control signal prior to its entry into the SWITCH TUBE DRIVER.

The overall objective of these two circuits is to blank out a portion of the No. 1 video picture in accordance with the information conveyed by the No. 2 channel and to have the blank space filled with video information furnished by the No. 2 Channel.

The object of this paper is to give a description of the developmental problems encountered, together with their solutions. In most cases the method used in arriving at a finished circuit is not classical but represents how electronic circuits are developed when time is limited. The

final equipment leaves much to be improved. Each circuit should eventually be redesigned in the light of its contribution to the overall amplifier with a more rigorous evaluation of its transient behavior in the dynamic state.



BLOCK DIAGRAM OF MONTAGE AMPLIFIER

J. A. Cooper | May 20, 1950

Figure 1

CHAPTER II

INPUT VIDEO AMPLIFIERS

Specifications for the video inputs required that they accept a noncomposite, black negative, video signal from a 75 ohm coaxial line. This signal would be expected to range from $\frac{1}{2}$ to 2 volts peak-to-peak. The output of the stage must feed the mixer with a constant peak-to-peak output voltage. It is therefore required that the input video stage also act as the variable gain stage for the unit.

In order to avoid the use of a complex, capacity-compensated, voltage divider or an expensive low-impedance pad as a gain control, it was decided to use a suppressor gain control. This type of control can be designed to preserve good linearity in grey levels and at the same time have the desirable feature of being a d-c control, making remote operation possible.

Since many sharp cutoff pentodes have rather ineffective suppressors, as far as a transconductance control is concerned, the choice of tube types narrowed to the 6AS6 as the best miniature tube for the purpose.

It has been shown (Grob [2]) that low-gain, shunt peaking gives the best response, in both frequency and time delay, of any practical method of video peaking. Shunt peaking was chosen for this reason. With an estimated 20 micro-microfarads total plate load capacity and an upper cutoff of 10 megacycles, the plate load resistance was found to be:

$$R_L = 0.85\ X_C \quad (\text{at } f_2)$$

$$= \frac{.85}{2\pi(20 \times 10^{-12})(10^7)} = 671\ \Omega$$

The nearest standard value is 680 ohms and this was chosen as the value of the plate load resistor.

From the tube data, it was estimated that the tube would operate at a transconductance of about 3500 micromhos maximum and this would give a mid-frequency gain of:

$$\begin{aligned} \text{gain} &= g_m R_L \\ &= (3500 \times 10^{-6})(680) = 2.38 \end{aligned}$$

The mid-frequency gain was later measured on the final model and found to be 2.2.

A computation of the required amount of shunt peaking (Grob [1]) gave:

$$\begin{aligned} Lo &= 0.42\ C R_L^2 \\ &= (.42)(20 \times 10^{-12})(680)^2 = 3.84\ \mu h \end{aligned}$$

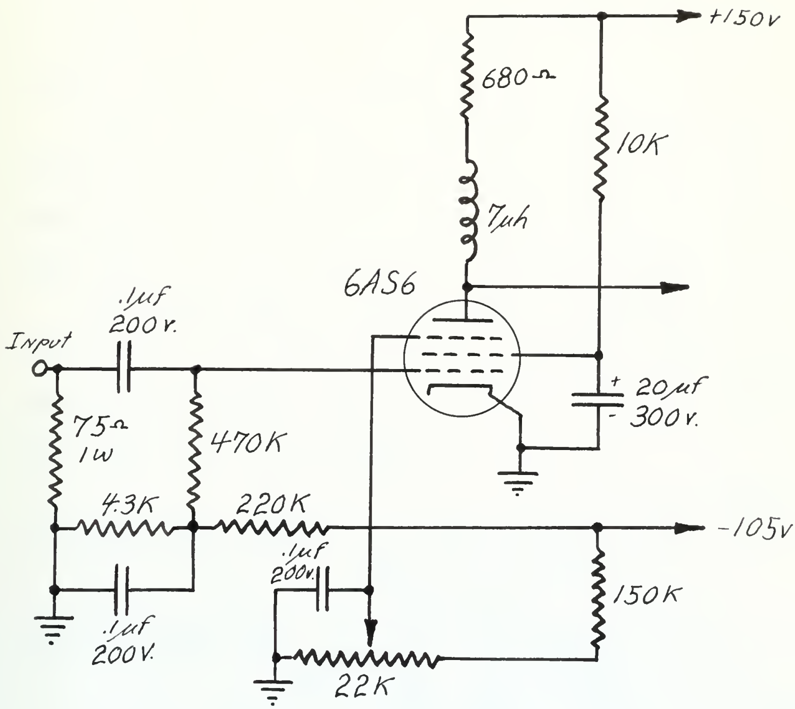
The nearest stock value of peaking inductor was 7 microhenrys and this was chosen as the final value for the peaking inductor.

In order to provide a variable suppressor gain control operating from a standard -105 volt supply, a 22,000 ohm potentiometer was placed in series with the 150,000 ohm resistor. This gives a "no-load" current drain of 0.61 milliamperes and a voltage variation at the suppressor of from zero to -13.42 volts. A negative voltage is thus available which exceeds the guaranteed plate current cutoff by the suppressor of the

6AS6 tube.

The grid bias was chosen to be at about -2 volts and the screen dropping resistor was chosen to give 120 volts on the screen as recommended by the tube data.

The final circuit was as shown in Figure 2.



INPUT VIDEO AMPLIFIER

FIGURE 2

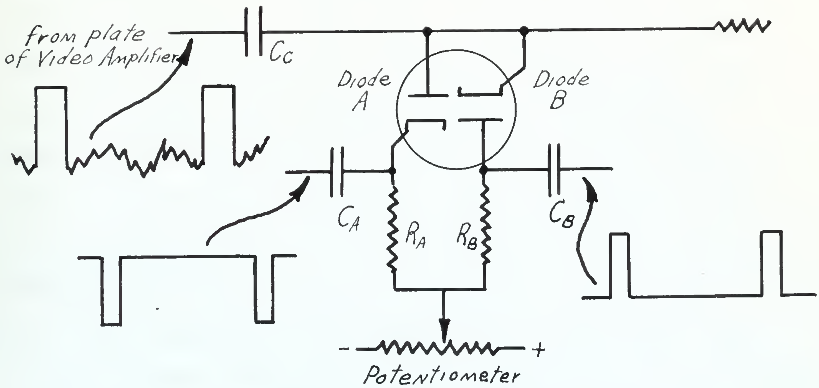
CHAPTER III

KEYED CLAMP

In order to properly mix two video pictures and form a montage of the two, accurate control of the d-c component in each picture is required. To analysis this, use is made of the black level, or, more accurately, the blanking level as a reference from which the white intensity, and consequently various shades of grey, are matched.

Once the black level of each picture is established and matched in the mixer output the proper match of the white level may be achieved by an independent setting of the a-c video gain in each of the VIDEO AMPLIFIERS feeding the MIXER.

The KEYED CLAMP is a device used to accurately fix the voltage level of blanking interval in each of the two incoming video signals. The basic circuit, with the applied wave forms, is shown in Figure 3.



FUNCTIONAL DIAGRAM OF KEYED CLAMP

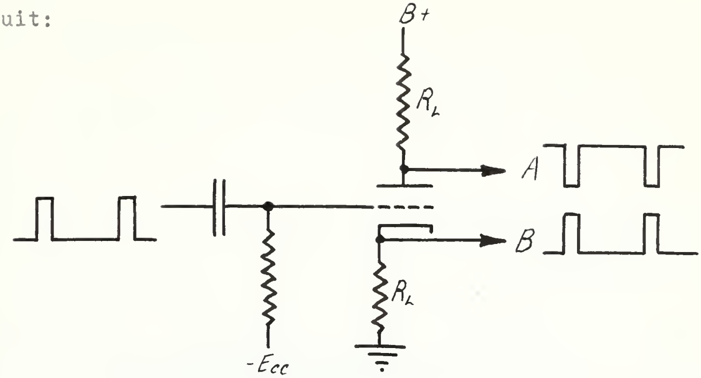
FIGURE 3

The desired d-c level of the mixer grid is set by adjustment of the potentiometer, and pulses of equal amplitude, coincident in time, but of opposite polarity are applied to the twin diodes. Note that the polarity of the pulses are in the proper direction to cause conduction of the diode at the peak of each pulse, thereby fixing the potential of the mixer grid at the time of each pulse. This potential will equal the potential set on the potentiometer if the pulses are of equal amplitude and the circuit is balanced with equal components in each branch. In the actual circuit, the pulses are derived from a negative sync source which is phased to occur during each blanking interval of the video picture information. Note that no other form of grid return is supplied except through the diodes. Since the diodes are not conducting during the time when picture information is passing, the actual time constant of the grid circuit is practically infinite for the video picture information. This makes it possible to choose a very small capacitor as the coupling condenser (C_c) and thereby minimize the leakage resistance to the driver plate. The overall action of this circuit is to supply a charge to the coupling condenser (C_c) at the end of each picture line which is equal to its loss of charge through leakage during the passage of the picture information. This fixes potential of the grid at the chosen value during the blanking interval which is independent of the picture information carried by the video signal.

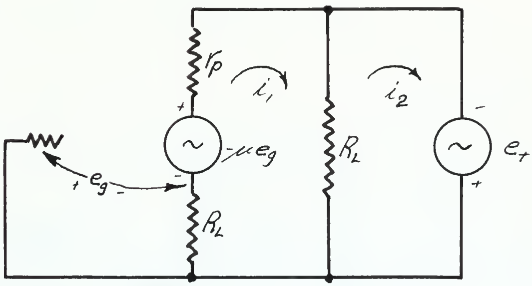
The equal pulses in phase opposition are derived from

a triode phase splitter of the conventional type, utilizing equal plate and cathode load resistors. An analysis of the output impedance from such a phase splitter is of value in arriving at a practical design.

Circuit:



Equivalent Circuit (to find the impedance of the "A" output):



Loop equations:

$$(2R_L + r_p)\, i_1 - R_L\, i_2 = -\mu e_g$$

$$-R_L\, i_1 + R_L\, i_2 = e_t$$

but, $\quad e_g = R_L\, i_1$

So that the equations become

$$[(2+\mu)R_L + r_p]i_1 - R_L i_2 = 0$$

$$-R_L i_1 + R_L i_2 = e_t$$

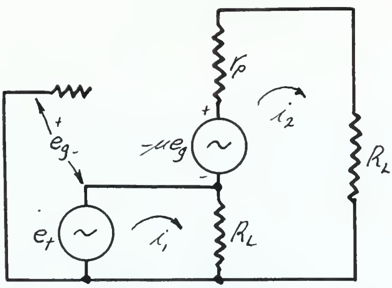
$$i_2 = \frac{\begin{vmatrix} (2+\mu)R_L + r_p & 0 \\ -R_L & e_t \end{vmatrix}}{\begin{vmatrix} (2+\mu)R_L + r_p & -R_L \\ -R_L & R_L \end{vmatrix}} = \frac{[(2+\mu)R_L + r_p]e_t}{[(2+\mu)R_L + r_p]R_L - R_L^2}$$

$$\text{Output impedance } (Z_A) = \frac{e_t}{i_2} = \frac{[(2+\mu)R_L + r_p]R_L - R_L^2}{(2+\mu)R_L + r_p}$$

$$Z_A = \frac{[(1+\mu)R_L + r_p]R_L}{[(2+\mu)R_L + r_p]}$$

Note that if μ is large, the output impedance becomes approximately equal to R_L.

Equivalent circuit (to find the impedance of the "B" output):



Note that:

$$e_g = -e_t$$

Loop equations:

$$R_L i_1 - R_L i_2 = e_t$$

$$-R_L i_1 + (2R_L + r_p) i_2 = -\mu e_g$$

$$= \mu e_t$$

So that;

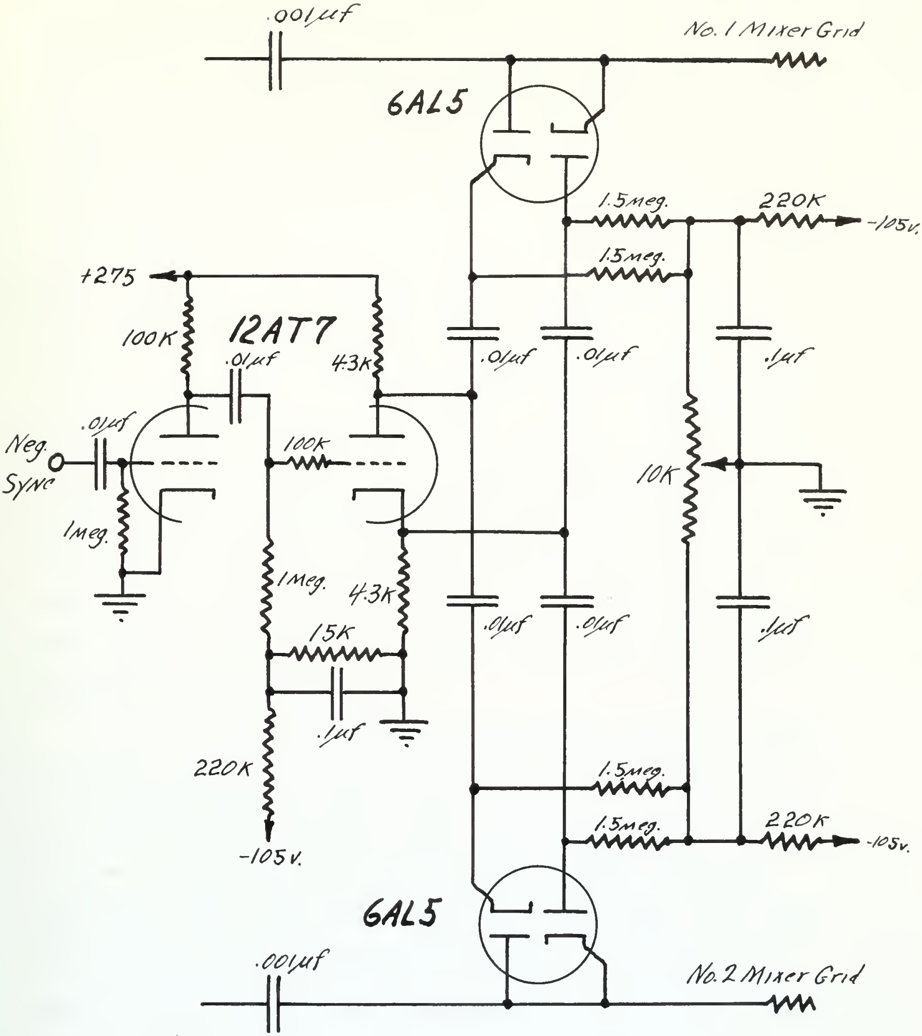
$$i_1 = \frac{\begin{vmatrix} e_t & -R_L \\ \mu e_t & 2R_L + r_p \end{vmatrix}}{\begin{vmatrix} R_L & -R_L \\ -R_L & 2R_L + r_p \end{vmatrix}} = \frac{(2R_L + r_p)e_t + \mu R_L e_t}{(2R_L + r_p)R_L - R_L^2}$$

$$Z_B = \frac{e_t}{i_1} = \frac{(2R_L + r_p)R_L - R_L^2}{(2R_L + r_p) + \mu R_L}$$

$$= \frac{(R_L + r_p) R_L}{(2 + \mu)R_L + r_p}$$

If μ is large the output impedance becomes approximately,

$$Z_B \cong \frac{R_L + r_p}{2 + \mu}$$



THE KEYED CLAMP

FIGURE 4

A consideration of the output impedance of these signal generators gives many of the answers as to the proper choice of components. Since the generators are basically unbalanced, it becomes necessary to have light dynamic loading to insure that equal voltages are being developed. This consideration leads to the choice of 1.5 megohms as the values for R_A and R_B in Figure 3. Even with a light balanced load formed by R_A and R_B, unbalance will occur if the charging current supplied to C_c is very great. For this reason, a high quality coupling condenser of low leakage resistance is required. A 0.001 microfarad mica condenser was found to be ample and gives the low leakage desired. Needless to say, it is imperative that the plate and cathode load resistors of the phase splitter remain equal and be small compared to the dynamic load. This lead to the choice of matched 4,300 ohm, 5%, 2 watt resistors for this purpose.

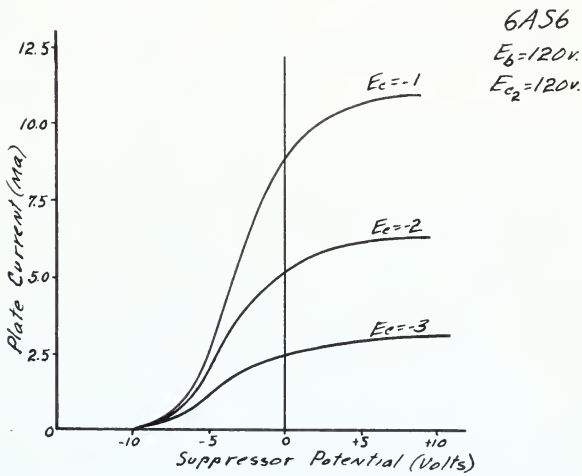
The SYNC AMPLIFIER was designed to be tolerant of the input sync amplitude, which may be expected to vary from 3 to 8 volts peak-to-peak. With the chosen 12AT7, about -5 volts is required for plate current cutoff, but when amplified, even the 3 volt input will give over a 100 volt pulse on the plate. Since these pulses are clipped by a 100,000 ohm clipping resistor in the grid circuit of the phase splitter, there is ample leeway to insure a constant output from the phase splitter regardless of fluctuations between the stated limits of input amplitude.

The complete circuit of the KEYED CLAMP, shown in Figure 4, controls the black level match of the video signals when viewed by the common mixer plates.

CHAPTER IV

VIDEO MIXER

It is the purpose of the MONTAGE MIXER to pass either #1 video or #2 video channel with a minimum transient, resulting from the switching process. To accomplish this function, the suppressor grid was used as the switching control, by the application of equal and opposite square waves to these elements. Two 6AS6 tubes were used with a common plate load and with variable bias in their control grids, so that the plate current could be matched in each. The feasibility of this switching scheme is apparent from the plate current vs. suppressor voltage characteristics in Figure 5.

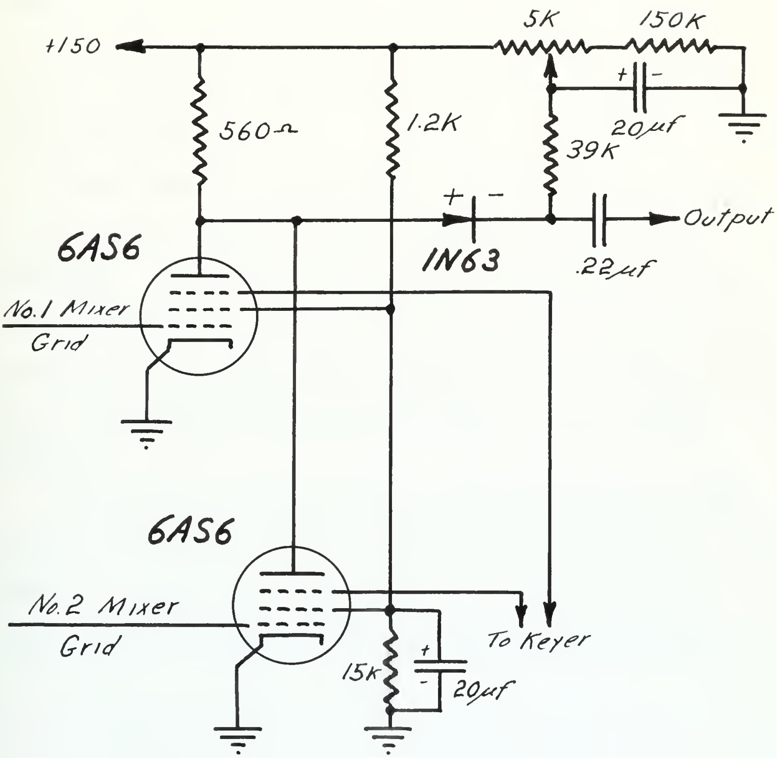


6AS6 SUPPRESSOR CHARACTERISTICS
FIGURE 5

With the tube operating normally with a control grid bias of about -2 volts and a screen voltage of 120 volts, the plate current will be cut off when the suppressor potential is dropped below -10 volts. The grid #1 to plate transconductance curves, not shown in Figure 5, behave in a similar manner and were discussed in the chapter on INPUT VIDEO AMPLIFIERS. Assuming that it is possible to get a steep wave front square wave on the suppressor which would suddenly change its potential from the normal operating value of zero to a negative value below -10 volts, it is clear that the tube would act as an adequate video switch. In the MONTAGE AMPLIFIER two of these tubes with common plates effect the switch between video channels. The way in which the two video signals are applied to the control grids was discussed in the chapter on the KEYED CLAMP. Calculation of the plate load resistance and shunt peaking was performed as discussed in the chapter on VIDEO AMPLIFIERS.

Even with the rather elaborate KEYER CIRCUIT driving the suppressors, the transient in the mixer output was not within tolerable limits. Although the observed plate transient was less than a tenth of a microsecond in total duration, its peak amplitude was in some cases greater than the peak-to-peak video signal being passed. This condition could not be tolerated because any spike below the blanking level would upset the positive action of following clamps. To eliminate any possibility of the "spike" being passed on to the output stages, a series diode clipper was used. Provision was made to adjust this clipping level so that whenever the plate dropped below

the set clipping level the diode would cease to conduct and effectively decouple the mixer plates from the OUTPUT VIDEO AMPLIFIER. The overall circuit of the mixers, together with the diode clipper, is shown in Figure 6.



THE VIDEO MIXERS

FIGURE 6

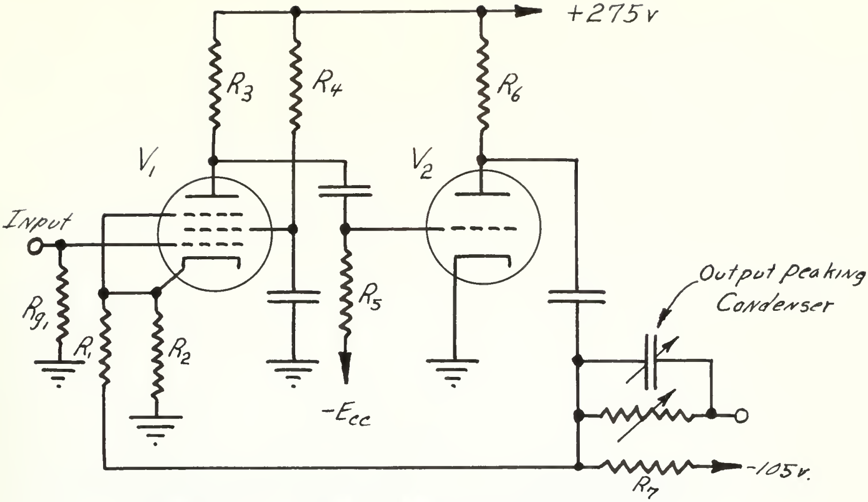
CHAPTER V

VIDEO OUTPUT FEEDBACK AMPLIFIER

The output specifications for a studio video amplifier are rather rigorous. The requirements include an essentially constant generator impedance of 75 ohms in order to properly feed a coaxial video cable. This insures that no reflections will appear at the receiving end as the result of a minor discontinuity, such as a patch panel between the sending and receiving ends.

Many forms of low impedance generators are possible but all suffer rather violent impedance changes with frequency. For this reason a very low impedance generator is preferable, since, for instance, a 2 ohm generator may vary as much as 100% as the frequency is changed, yet vary less than 3% when viewed through a 73 ohm series resistor.

The actual circuit design of this feedback amplifier was not done by the author. However, one logical approach would be to find just what circuit parameters are of importance in arriving at a truly low output impedance.

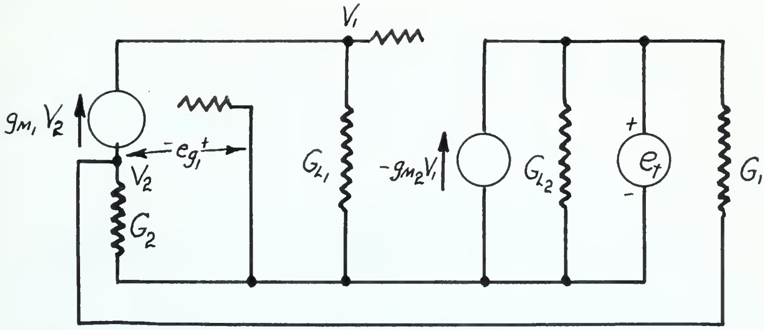


ELEMENTARY FEEDBACK AMPLIFIER CIRCUIT.

FIGURE 7

At center frequency we may assume that all condensers shown in Figure 7 except the output peaking condenser, are of very low impedance compared to their associated circuits. R_{g_1} may be disregarded in comparison to the impedance of the signal source and the R_3R_5 parallel combination designated as the plate load of V_1. In the same manner, R_6 and R_7 combine to form the plate load of V_2.

Equivalent Circuit:



Nodal equations:

$$G_{L_1} V_1 = g_{m_1} V_2$$

$$(G_1 + G_2) V_2 - G_1 e_t = -g_{m_1} V_2$$

Solving:

$$V_1 = \frac{\begin{vmatrix} 0 & -g_{m_1} \\ G_1 e_t & G_1 + G_2 + g_{m_1} \end{vmatrix}}{\begin{vmatrix} G_{L_1} & -g_{m_1} \\ 0 & G_1 + G_2 + g_{m_1} \end{vmatrix}} = \frac{g_{m_1} G_1 e_t}{G_{L_1}(G_1 + G_2 + g_{m_1})}$$

$$V_2 = \frac{\begin{vmatrix} G_{L_1} & 0 \\ 0 & G_1 e_t \end{vmatrix}}{\begin{vmatrix} G_{L_1} & -g_{m_1} \\ 0 & G_1 + G_2 + g_{m_1} \end{vmatrix}} = \frac{G_1 \cancel{G_{L_1}} e_t}{\cancel{G_{L_1}}(G_1 + G_2 + g_{m_1})}$$

The impedance as viewed by the generator is the ratio of its voltage (e_t) to its current (i_t). When expressed in terms of admittance, the relation is:

$$G = \frac{i_t}{e_t} = \frac{G_{L_2} e_t + G_1(e_t - V_2) + g_{m_2} V_1}{e_t}$$

Substituting:

$$G = G_{L_2} + G_1 - \frac{G_1^2}{G_1 + G_2 + g_{m_1}} + \frac{g_{m_1} g_{m_2} G_1}{G_{L_1}(G_1 + G_2 + g_{m_1})}$$

Examination of this equation indicates that if G is to be large, G_{L2}, G_1, G_2, Gm_1 and Gm_2 should in general, be large while only G_{L1} should be small. Substituting practical values indicates that the last term is of major importance in this expression. Since the last term is proportional to the ratio of Gm_1 to G_{L1}, this practically dictates the use of a high gain pentode as V_1, while V_2 requires only high transconductance. The ratio $\frac{G_1}{G_1 + G_2}$ is inversly related to the overall gain and is dictated largely by the gain desired.

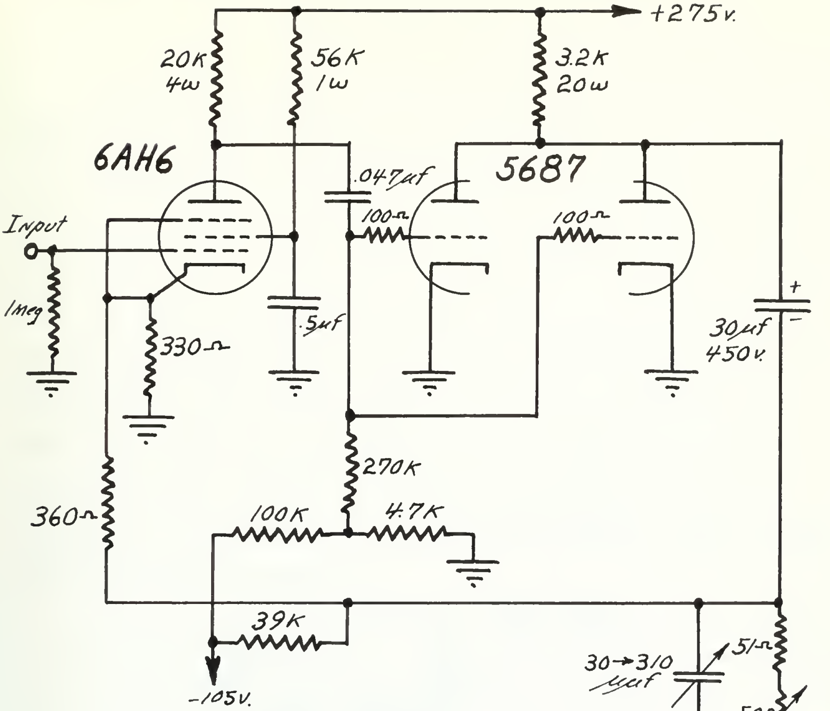
An exact analysis of this circuit is difficult since the final model has parameters which vary widely with frequency such as the interstage coupling between the two tubes and the screen grid by-pass on the pentode. However, the substitution of nominal values in the impedance equation gives an output impedance of only 2.37 ohms which is of the order of magnitude determined by actual test.

This low value of output impedance may be expected to rise at the higher frequencies and, in order to partially compensate for this rise, the variable condenser in parallel with the output resistance is used to lower the value of artificially added series impedance, thus maintaining an essentially constant generator impedance of 75 ohms.

In picking tubes to physically realize the output required, one's attention is brought immediately to the output triode. This tube must deliver at least a 2 volt peak-to-peak video signal to a 75 ohm line. Referring to the circuit in Figure 8, the major a-c plate load is the 75 ohm line in series with approximately 70 ohms of added resistance. Of next importance is the parallel combination of the feedback voltage divider, R_1 and R_2 which, in the final model, was 360 ohms and 330 ohms respectively. The above mentioned loads combine in parallel to form a dynamic load of only 78 ohms. A change of current through this load in excess of 25 milligrams is required in order to produce a 2 volt peak-to-peak signal output. This requirement alone would justify the choice of the parallel connected 5687 as the only miniature type capable of delivering this magnitude of current with the desired linearity.

Many types of high gain pentodes are available for the voltage amplifier. Among the more popular is the chosen 6AH6 which has a high transconductance and low interelectrode capacity. Relatively high gain may be realized by this stage, as the very heavy overall voltage feedback will materially help in obtaining the desired overall band width.

The final circuit used is shown in Figure 8.



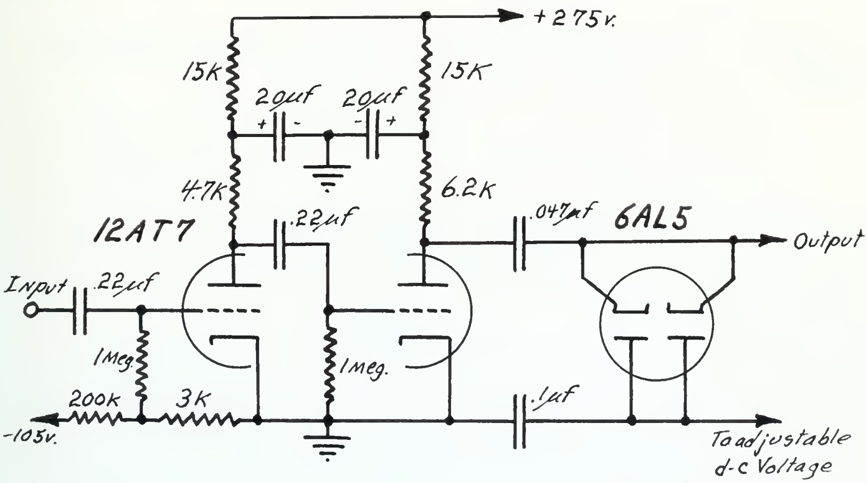
VIDEO OUTPUT FEEDBACK AMPLIFIER

FIGURE 8

CHAPTER VI

CONTROL VIDEO AMPLIFIER

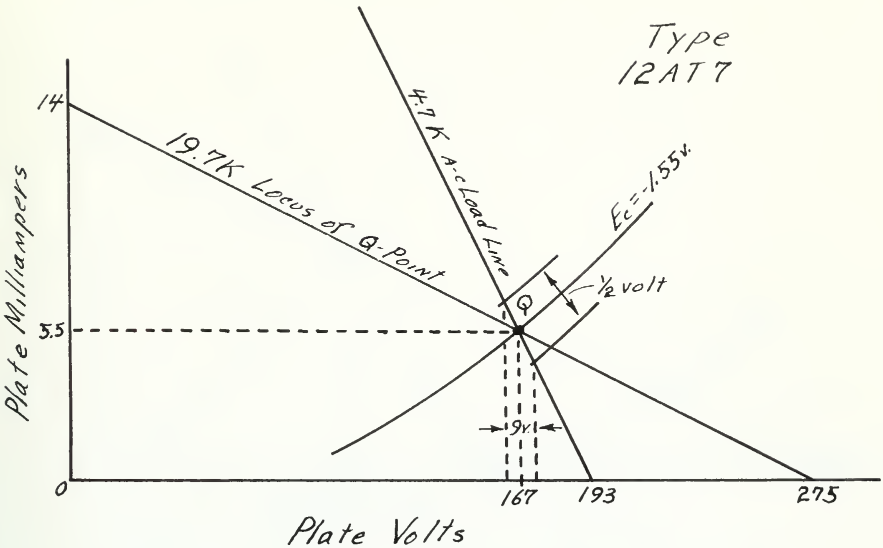
In order to supply a suitable signal to the 6BN6 SWITCH TUBE, which requires about a 4 volt change on its limiter grid to complete the switching process, a CONTROL VIDEO AMPLIFIER is required. Because the video input may be expected to be as low as ½ volt peak-to-peak, the gain of this stage must be large, in order to insure that the above mentioned 4 volt transition represents a small percentage of the original peak-to-peak video signal. Another consideration is that the peak voltage limitation on the 6BN6 input is 50 volts. To meet these requirements, a graphical design, based on the plate characteristics of a 12AT7, leads to the circuit shown in Figure 9.



CONTROL VIDEO AMPLIFIER

FIGURE 9

The graphical solution for the gain of V_1 is shown in Figure 10.

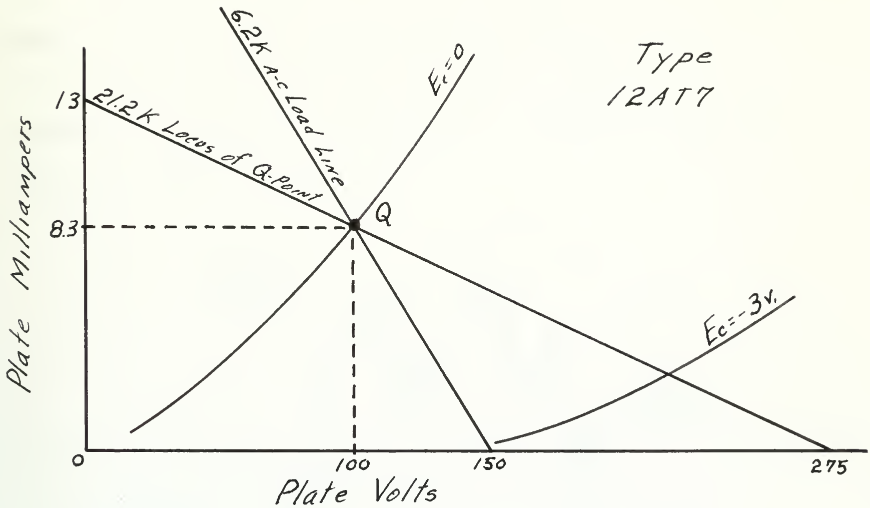


GRAPHICAL SOLUTION OF FIRST
CONTROL VIDEO AMPLIFIER

FIGURE 10.

It is seen that a mid-frequency gain of approximately 18 may be expected from V_1. The blanking period is positive when applied to the grid of V_2 and this flat topped wave will clamp at $E_c = o$.

Figure 11 shows the expected operation of V_2.



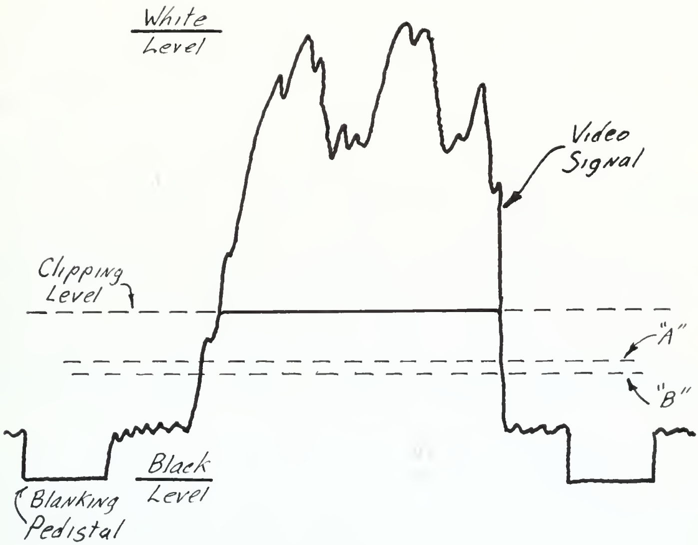
GRAPHICAL SOLUTION OF SECOND
CONTROL VIDEO AMPLIFIER

FIGURE 11.

If the MONTAGE insert is small compared to the entire field, then the Q-point will remain close to $E_c = o$ which represents the black level of the picture information. From Figure 11 we see that grid cutoff will occur at about -3 volts and the total peak-to-peak plate signal will be about 50 volts as desired.

There is present in the plate circuit of V_2 only about 1/3 of the total peak-to-peak video information. This portion is in the dark grey and black regions, the light grey and white tones having been clipped.

This 50 volt peak-to-peak signal must have a controlled d-c component in order to raise and lower the entire wave form at will, thus allowing channel switching to occur at any desired switching level in the wave form. The overall action is clarified by reference to a typical horizontal line as shown in Figure 12.



CONTROL VIDEO AMPLIFIER WAVEFORMS

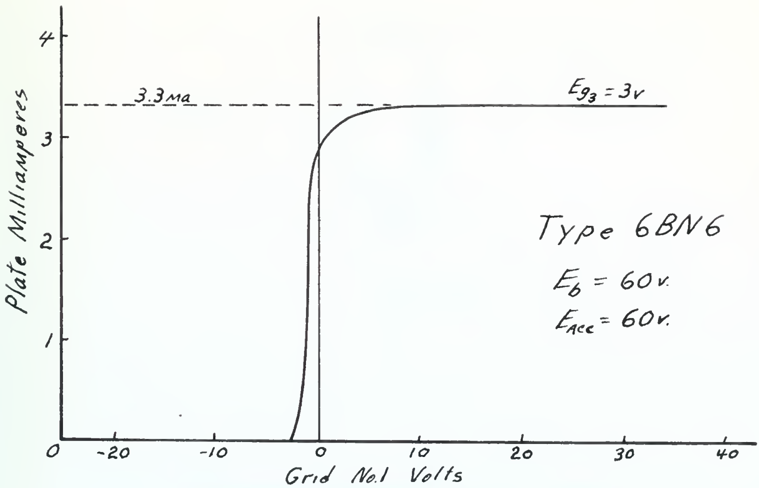
FIGURE 12

In this drawing, the "A" level is the d-c voltage, which must be exceeded in order to switch the #2 video channel "on". The "B" level is spaced at a finiate d-c voltage below the "A" level and is the value below which the video level must fall in order to switch the mixers back to the main picture. It is desirable to have some control over this switching level so that a comfortable margin between the grey background and the switching levels may be set for each type of MONTAGE insert. Since the d-c levels of "A" and "B" are fixed by the bias applied to the 6BN6 switch tube, it becomes necessary to clamp the entire wave form at some adjustable d-c level. For this service a diode clamp operating on the blanking pedistal is used. A parallel connected 6AL5 diode with an adjustable bias performed satisfactorily after d-c isolation from the plate of V_2 through a 0.047 microfarad coupling condenser. By adjusting the d-c bias applied to the diode plates, the entire video wave form is effectively raised or lowered across the switching threshold, thus allowing complete control of the grey level at which channel switching occurs.

CHAPTER VII

SWITCH TUBE

The heart of the MONTAGE AMPLIFIER is the switch tube which must extract from the control video signal the necessary information for the switching of video channels. Of all the tubes currently available, only the new gated beam discriminator (Adler [17]) developed by Dr. Adler of the Zenith Corporation showed promise of being a practical switch tube. Although the 6BN6 was designed to act as a discriminator, inspection of its published characteristics (Figure 13) shows its value as a square wave generator, which is essentially its function in the MONTAGE AMPLIFIER application:

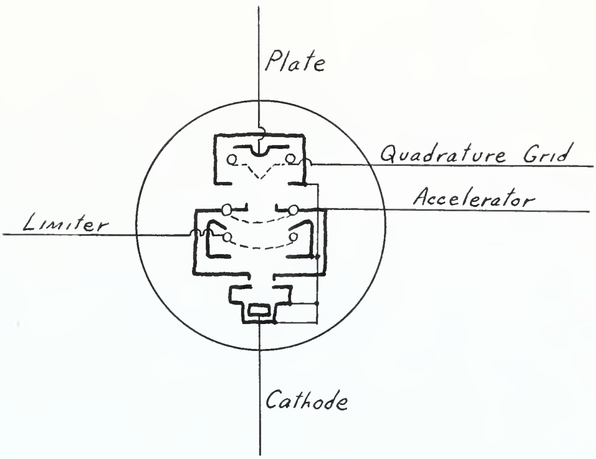


TYPE 6BN6 PLATE CHARACTERISTICS

FIGURE 13

Due to the limited data available on this type, much of the finished design was the result of trial and error experiements which will not be repeated here in detail. However, in order to arrive at a practical design some knowledge of the tube's structure and theory of operation is useful.

The examination of the tube's internal structure (Figure 14) shows that it is of the beam type with the beam generated in much the same manner as in a cathode ray tube.



INTERNAL STRUCTURE OF THE 6BN6

FIGURE 14

The electron beam is generated by a gun structure near the cathode. This beam, after being accelerated, passes through the limiter grid and quadrature grid enroute to the plate. If the limiter grid is negative, the beam is repelled to the nearest positive element (the accelerator). As this beam passes the limiter, a negative voltage on the quadrature grid will repel the electrons to the accelerator structure. Thus the tube forms a coincidence gate where both the limiter and quadrature grid must be positive in order to have plate current. Since the beam density is primarily controlled by the gun structure in conjunction with the accelerator voltage, it may be visualized how the step function of Figure 13 is caused. After the limiter is positive any further increase in its potential will not increase the beam current; that current being fixed by the gun structure and accelerator voltage.

All is not ideal, however, with this arrangement, since it was found that when the limiter grid is positive it draws considerable current. Although this current was only 500 microamps, it remained essentially constant when plotted against limiter grid voltage in the positive region. Since the grid impedance is the rate of its current to voltage, the impedance change with grid potential is rather violent, being infinite for negative values of grid voltage, then suddenly becoming very low at the transition into the positive region, and thereafter increasing proportionally with a further increase of limiter voltage. The effect of this

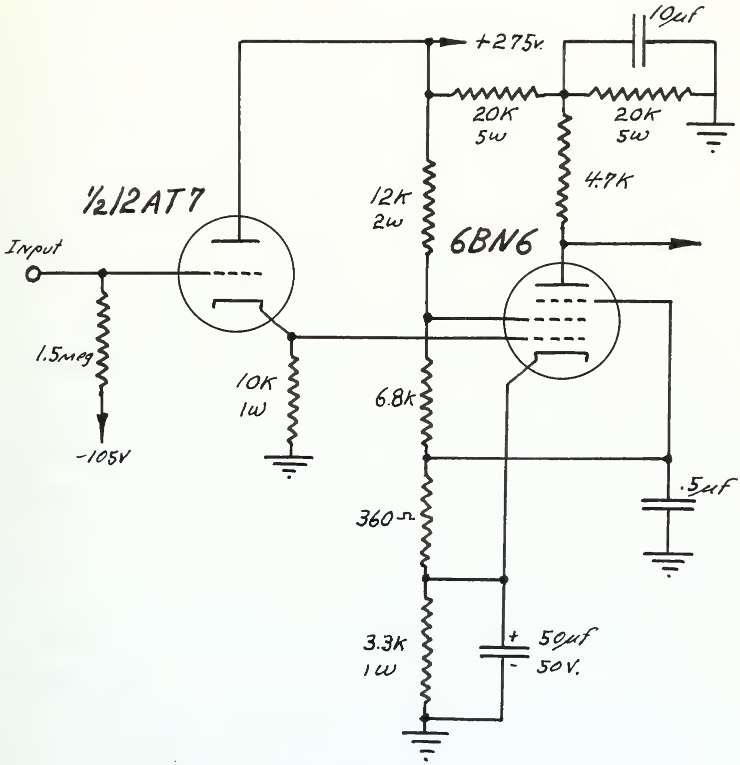
type of load on a generator with a finite impedance is to materially "flatten" the wave form at the transition point, spoiling the desired effect of square wave generation in the plate circuit. In other words, a sloping wave front applied to the limiter grid at best can cause only a proportionally steeper current wave front in plate current due to the finite rise time of the curve in Figure 13. Of course, any "flattening" of the wave front applied to the limiter grid is reflected in a reduction of the current rise time in the plate circuit and spoils the square wave action of the tube. In order to minimize this effect, a cathode follower was used as a driver for the grid, since its low output impedance tended to minimize the effect of violent changes in limiter grid impedance with signal voltage.

In addition to this difficulty with the limiter grid drive, it was found that the dynamic plate resistance was also subject to violent changes with plate current, which meant that a square-topped voltage wave could not be obtained from even a reasonably small plate load resistor. It was observed that if about a 10 volt square wave was desired from the plate in response to a sinusoidal input on the limiter grid, the resultant wave form had about a 10% sag during plate current flow. This was probably due to defocusing action of the limiter grid at high values of potential such as would be encountered at the peak of the input sine wave.

The overall result of this study was to discount the possibility of using the square waves generated by the

6BN6 directly on the suppressor grids of the mixers without further wave shaping in the following circuits.

The final form of the 6BN6 switch tube together with its cathode follower drive is shown in Figure 15 and represents the outcome of considerable cut-and-try laboratory work in arriving at an acceptable switch circuit.



SWITCH TUBE AND INPUT DRIVER CIRCUIT

FIGURE 15

CHAPTER VIII

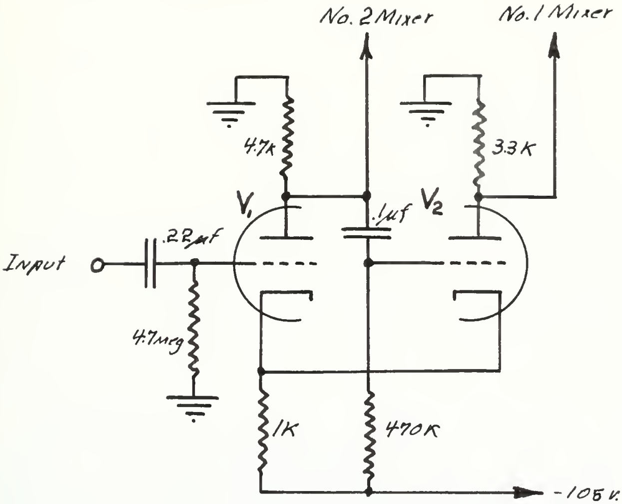
MIXER KEYER

As was pointed out in the section on the 6BN6 TRIGGER TUBE, the wave-form of the trigger output was not an ideal square wave, but had very rounded corners. This could not be tolerated, since any departure from a true square wave, when applied to the mixer suppressors, could be expected to cause a bad transient in the plate current. Ideally, when one mixer is cut off by the sudden application of a negative voltage on its suppressor, the other mixer must be cut on so that a minimum transient will appear in the net plate current of the two mixers. This necessitates a KEYER circuit that can drive the mixer suppressor from cutoff to their normal operating potential in a very fast transition with a minimum of overshoot. In addition, the keyer must be able to handle a wide latitude of signals and deliver equal, but opposite, square waves to the two mixers in precise time phase.

The KEYER must be designed to have an "at rest" position in the absence of signals such that the #1 video channel is conducting and the #2 video channel is non-conducting.

Many types of KEYER circuits were tried before one was found that exhibited acceptable mixer switching. The final approach was to build a two stage resistance-coupled amplifier with one stage having a positive grid return and the other stage biased below cutoff. This configuration

used the twin triode type 12AT7 operating below ground potential from the -105 volt supply. All circuit values were varied in order to arrive at a final design that would produce the desired suppressor signals. The final circuit is as shown in Figure 16.



MIXER KEYER CIRCUIT

FIGURE 16

Note that the only change, outside of circuit constants, from the original resistance coupled amplifier is that there is no condenser across the 1K common cathode resistor, thereby providing coupling from V_1 to both the grid and to the cathode of V_2. This dual coupling speeds the transition and gives a close match of the mixer signal's leading edges. The relatively low values of plate load resistance insures quick relaxation of the plate back to ground potential when

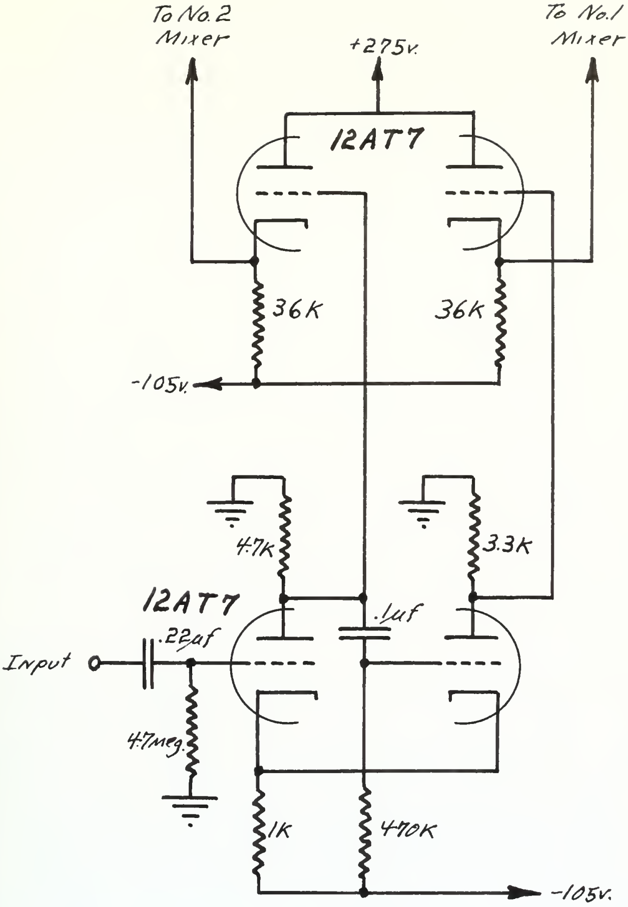
the plate current is cutoff. Since this circuit is designed so that either one tube or the other is on at any one time, the voltage drop across the 1000 ohm common cathode resistor is maintained at a sufficient value to insure that V_2 always has its grid returned to a potential that is below cutoff. V_1 has been provided with a larger value of plate load resistor than has V_2. This was experimentally found to be necessary in order to equalize the peak-to-peak voltages in the outputs. This difference of plate load resistors was due to two factors. First, the dynamic load of V_1, includes the following grid resistor of V_2 and, secondarily, when V_1 is cut off, the grid of V_2 goes into the positive grid region causing a larger voltage drop than is experienced by the plate of V_1.

A re-examination of the circuit indicates that it basically is a one-shot multivibrator with a very long gate compared to the maximum square wave gate that may be expected in MONTAGE signals. This multivibrator is driven in both directions by the incoming signals. It supplies square wave outputs whose positive cycles are fixed at ground potential.

The KEYER was found capable of driving the suppressor grids of the mixers satisfactorily except that extreme care had to be taken to minimize capacity in the wiring, as any capacity in the plate load would tend to slow the rise time of the plate voltage. In order to minimize the effect of shunt capacity, it was decided to put cathode followers in the KEYER outputs to act as MIXER DRIVERS. These cathode followers provide a much lower capacity loading to the keyer

than the mixer suppressors. In addition, the suppressor current is not negligible and prevented the suppressor from returning to ground potential at plate current cutoff of the KEYER. The cathode follower design was of the direct coupled type to preserve the ground reference and, although the outputs drive the mixer suppressors slightly positive, this is not objectionable in the final operation of the mixers.

The final overall circuit including the cathode follower drivers are shown in Figure 17.



MIXER KEYER AND SUPPRESSOR DRIVER
CIRCUIT

FIGURE 17

CHAPTER IX

VIDEO DELAY LINE

After completion of the MONTAGE AMPLIFIER in the "bread board" state, a final systems test showed an obvious oversight. Although the circuit did a good job of cutting a hole in the #1 video picture in response to the picture information in the #2 channel, the inserted video from the #2 channel did not fit exactly the hole cut. A careful check revealed that the time delay of a signal passing through the control channel to the mixer suppressors was greater than the signal direct to the mixer channel grid. This delay was measured and was found to be about two tenths to three tenths microseconds depending somewhat on the video level used to trigger. This fault was basic since the control video passed through about eight triodes enroute to the suppressor while the #1 video passed through only one tube to the grid. The obvious answer was to insert an appropriately designed delay line to slow the video enroute to the control grid of the mixer.

Much information has been written about delay lines for pulse work, but relatively little work has been done on delay lines for wide band video. One approach (Turner [4]) to the problem was to design a line with controlled mutual coupling between the inductances, as it is difficult to meet the mathematics of pure lumped constant line and avoid all mutual effects. This approach was considered but rejected because of the necessary size of the overall line.

It was decided to try to design a lumped constant line which would minimize the mutual coupling but be small in size. The final configuration of the line was dictated largely by the mechanical configuration of components that were available and secondarily by the electrical analysis of the problem.

Available in quantity were 22 micro-microfarad silver button mica condensers of the "lead through" variety and 25 microhenry coils of small dimensions. By application of the basic formulas of lumped constant lines (M.I.T. [3]) and the above mentioned constants, the following analysis was pursued.

Delay/Section $(\tau) = \sqrt{\ell c}$

$$= \sqrt{(25 \times 10^{-6})(22 \times 10^{-12})} = 0.02345 \, \mu\,\text{sec.}$$

Number of sections needed (N) $= \dfrac{.3}{.02345} = 12.8$ Sections

In order to provide sufficient margin for error 17 sections were built.

Terminating Resistance $(R_o) = \sqrt{\ell / c}$

$$= \sqrt{\frac{25 \times 10^{-6}}{22 \times 10^{-12}}} = 1066 \, \Omega$$

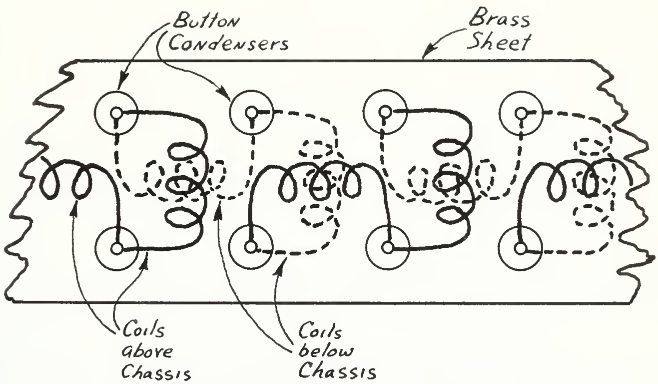
Cutoff frequency $(f_c) = \dfrac{1}{\pi \sqrt{\ell c}} = \dfrac{1}{\pi \tau}$

$$= \frac{1}{\pi (.02345 \times 10^{-6})} = 13.6 \text{ mc.}$$

With a theoretical cutoff of 13.6 megacycles, it was felt that adequate transmission could be realized of video picture information containing frequencies up to 8 megacycles. The frequency response was later measured and the first serious dip in the overall response was found to be about 7.5 megacycles or approximately $\frac{1}{2}$ of the cutoff frequency.

It was decided to make the line conform to basic π sections since this would keep all inductors the same value and provide for about 11 micro-microfarads of terminating capacity, this being below the expected input capacity of the input video amplifier.

In order to reduce the mutual effects it was decided to place the lead through capacitors in two rows on a piece of sheet brass with adjacent inductors mutually perpendicular. These pairs of two inductors were then alternated on the upper and lower side of the sheet brass which acted as an electrostatic shield. The final arrangement of components is shown in Figure 18.



MECHANICAL ARRANGEMENT OF
VIDEO DELAY LINE

FIGURE 18

The overall performance of this delay line was found to be satisfactory for the passage of a standard test pattern and maintained a horizontal definition of over 450 lines. The observed delay was not as much as computed and in the finished MONTAGE AMPLIFIER all 17 sections were used to provide the necessary delay.

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CHAPTER X

SUPPORTING CIRCUITS AND FINAL ADJUSTMENTS

In the preceding chapters all of the main functional blocks of the MONTAGE AMPLIFIER were discussed. There remains a discussion of only a few supporting circuits to complete the description of the entire unit.

The negative power supply was built out of stock parts that were readily available and is of conventional design. It utilizes a bridge type selenium rectifier isolated from the power line by a one-to-one power transformer. The filter is an RC type terminating in an OB2 voltage regulator which supplies a well regulated -105 volts to the chassis. The filaments for the unit are heated from the same power transformer.

The only tube not described in the preceding chapters is the V11B which is connected as a cathode follower and serves as a driver for the 12AT7 keyer circuit. This tube is the unused half of the 12AT7 serving as the switch tube driver and is not necessary in the circuit except that some steepening of the wave fronts to the keyer was detected when it was installed. Since this section of V-11 would be wasted if not used, it was decided to wire it in, although its contribution to the overall circuit is small.

There are two screw driver adjustments provided on the MONTAGE AMPLIFIER for setting the output impedance of the feedback output amplifier. The technique used for these adjustments is to connect an R.F. oscillator to the grid of

the 6AH6 in the input of the feedback amplifier and to supply sufficient signal to give about 2 volts r.m.s. at the video output terminal which is open circuited, except for the vacuum tube voltmeter. With a 1 megacycle signal applied, the output is loaded with a 75 ohm resistor to ground and the resultant voltage at the output terminals is adjusted by means of the 50 ohm varable series resistor until exactly one half of the open circuited voltage appears. This procedure is then repeated at 4.5 megacycles, using the varable condenser as the means of adjusting the voltage drop. Since there is considerable interaction between these controls, continued repetition at both frequencies is necessary in order to finally arrive at a setting which is right. In the final test, the open circuit voltage at both 1 megacycle and 4.5 megacycles should be reduced by exactly one half, when the 75 ohm terminating resistor is added. Of course these adjustments only insure a 75 ohm output at the two frequencies used for test but the deviation from 75 ohms will remain small throughout the video spectrum.

The following steps are taken in the setup of the equipment for MONTAGE use:

1. Connect the NO. 1 VIDEO INPUT to the studio camera chain supplying the desired non-composite background video.

2. Connect the NO. 2 VIDEO INPUT to the film camera chain supplying the desired advertising insert.

3. Check to be sure that the MONTAGE WIPE SWITCH is in the MONTAGE position.

4. Check to make certain that both of the video chains and the NEGATIVE SYNC INPUT are being driven from the same pulse generator for proper syncronization.

5. With the MONTAGE ON-OFF SWITCH (located on the control panel) in the OFF position and the CLIPPING BIAS adjusted for minimum voltage (counter clockwise) increase the NO. 1 GAIN CONTROL until a 2 volt peak-to-peak signal is obtained at the output as viewed on a calibrated studio wave-form monitor.

6. Check to make certain the wave form of the MONTAGE insert has its blanking and shading adjusted to provide a clean signal with the background in the bottom 10% of the wave-form as viewed by both the horizontal and the vertical wave-form monitors.

7. Turn the MONTAGE SWITCH on the control panel ON.

8. Adjust the #2 GAIN and BLACK LEVEL BALANCE controls until both the black and white levels are matched in the output and recheck for a standard 2 volt output.

9. Increase the CLIPPING BIAS (clockwise) until compression of the blanking pulse is noted on the wave-form monitor, then back off until the signal is just restored to its original form.

10. Adjust the MONTAGE CONTROL on the control panel until a clean clipping level is obtained as viewed on the picture monitor.

With the above mentioned adjustments, the unit is ready for use and the MONTAGE may be inserted at will by use of the ON-OFF SWITCH on the control panel.

CHAPTER XI

CONCLUSION

The circuits described in the preceding chapters combine to form a special effects amplifier that is not limited to MONTAGE inserts. In addition, it is capable of inserting lettering, in either black or white, on a background picture by supplying the desired lettering only to the CONTROL VIDEO INPUT. This application requires no video input to the #2 video channel. By adjusting the black level balance control, the letters may be presented at either white or black level at will.

The MONTAGE AMPLIFIER may be used to form many wipe effects by supplying a suitable wipe signal to the control channel from an external circuit or from a black and white film operating from a flying spot scanner. In the case of film, the flying spot scanner is necessary in order to have good control of the d-c componant.

Further applications of the principals involved may provide a means of "cleaning" a radar picture by rejection of "grass" while passing square pulses of strong targets on to the video repeater. This same ability to steeper wave fronts may provide a superior means of relaying pulse information as in teletype or other forms of pulse code modulation.

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